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THE TELESCOPIC ALIDADE AND THE PLANE TABLE AS USED IN TOPOGRAPHIC AND GEOLOGIC SURVEYS

KIRTLEY F. MATHER AND BRADFORD WASHBURN

Received March 4, 1938; published

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INTRODUCTION

It is the purpose of this paper to assemble in convenient form certain of the more successful methods of manipulating the telescopic alidade, which have been developed during the last few years by those who have been using this instrument in various kinds of field work. It is hoped that this presentation will be sufficiently simple to enable the beginner to make use of it, and at the same time sufficiently comprehensive to be a desirable reference work for the instrument man of wide experience. The paper does not include a complete description of field methods of mapping, either by traverse or triangulation; for such a description reference should be made to the works listed in the bibliography.

Much of the material here presented was published in 1919 in an article entitled "The Manipulation of the Telescopic Alidade in Geologic Mapping," this *Journal*, vol. 19, pp. 97–142. The continuing demand for that paper, long after the issue was exhausted, has led us to its revision and expansion. New mechanisms and new techniques perfected during the last few years make necessary many changes in the original paper and justify the new title. For invaluable assistance in the task of revision, we are deeply indebted to Professor John W. Howard of the Massachusetts Institute of Technology and Colonel James W. Bagley of the Institute of Geographical Exploration at Harvard University. We are also obligated to the E. R. Watts Company of London and to the United States Geological Survey for certain of the illustrations which have been added to the text.

PART I. DESCRIPTION OF THE ALIDADE

The telescopic alidade consists essentially of a telescope attached by a transverse axis to a base plate, one edge of which bears a fixed and approximately parallel relation to the line of sight, and so supported as to permit the telescope to be elevated or depressed in a vertical plane. One of the most effi-

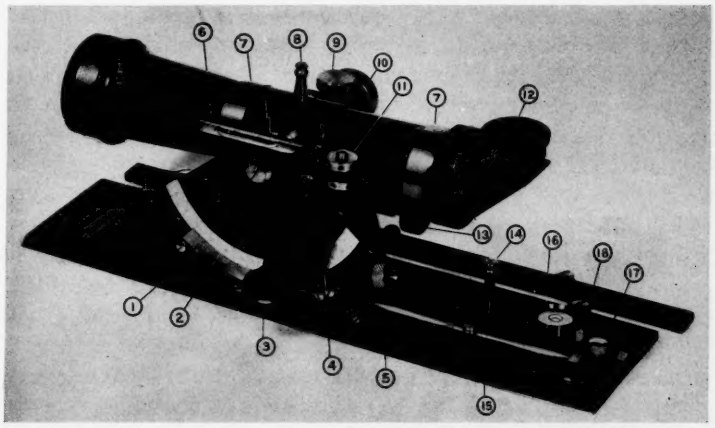


FIG. 1. THE TELESCOPIC ALIDADE MANUFACTURED BY E. R. WATTS AND SON, LONDON

Photograph from Institute of Geographical Exploration, Harvard University

1, vertical arc vernier; *2*, vertical arc; *3*, magnifier for reading arcs; *4*, Beaman stadia arc; *5*, tangent screw for vernier control bubble; *6*, vernier control level bubble; *7*, sleeves to hold wyes of striding level; *8*, clamping post for striding level when in use; *9*, clamp for vertical movement; *10*, focusing screw; *11*, capstan screw for adjusting level bubble; *12*, diagonal eyepiece; *13*, tangent screw for vertical movement; *14*, clamping post for striding level when not in use; *15*, trough compass; *16*, bullseye level; *17*, clamp screw for compass needle; *18*, parallel rule.

cient of the many different models on the market is shown in figure 1.

The complete instrument weighs about 3 pounds, stands between 3 and 4 inches in height, and is 10 to 12 inches in length. It is fitted into a sole-leather case with shoulder strap for carrying in the field.

1. *The Telescope* is a metal tube fitted with an object-glass at one end, an eyepiece at the other, and between the two a reticule holding cross-hairs. The object-glass ordinarily comprises a crown lens and a flint lens so shaped and arranged as to gather the rays of light from an object and form a small inverted image in the plane of the cross-hairs. These lenses are contained in a separate smaller tube which may be slid in or out of the telescope tube by means of a rack and pinion turned by the focusing screw on one side of the telescope in front of the transverse axis. This is necessary to define sharply the image of distant or near objects at will, or in other words to provide a means of bringing the objects in the field of vision into focus. Many of the more recently designed telescopic alidades employ an internal focusing system in which the object lens is immovable and all focusing of the image is done by means of a knurled-head tangent-screw which usually projects from the right side of the horizontal axis of the telescope (see fig. 1).

The eyepiece is similar to that of a microscope; its purpose is to magnify the cross hairs and the image thrown by the object-glass. It may be adjusted to suit the eye of the individual observer by twisting the knurled ring at the near end of the telescope tube. This shifts the eyepiece toward or away from the cross hairs. Once properly adjusted there is no reason for changing the position of the eyepiece unless the instrument is used by another observer.

At the ocular end of the eyepiece is a fixed prism which deflects the rays of light at right angles to their line of passage through the telescope and at the same time produces an erect image of the field. All observations are to be made while the operator is looking directly down into the eyepiece prism. Some alidades are fitted with a "periscope" or tubular roof above the eyepiece prism in which is housed a lens for the reversal of the image. When this is wanting, images in the field appear right side up but reversed from right to left. To keep maximum illumination of an undistorted field as observed through a roofed prism entails precision grinding of the highest order of merit; this is

obviously very expensive so that there exists some doubt as to whether it actually pays to correct the relation of the elements of the field in this particular.

2. *The Cross-Hair Ring,* or reticule, is placed so that the hairs will fall exactly in the focal plane of the object-lens as well as at a focus of the eyepiece. Its position is indicated by four capstan-head screws on the outside of the telescope tube. The cross hairs are spider webs, or very fine platinum wires, almost invisible to the unaided eye. They are generally four in number and are fastened immovably with shellac to the brass ring before it is inserted in the telescope. Very often on modern instruments, the "hair-wires" are etched on a glass reticule, similarly fastened to a metal ring. Two of the hairs cross the center of the ring at right angles to each other; their purpose primarily is to define the line of sight. The other two are parallel to one of these and spaced equidistant on either side of it; they are the *stadia hairs* and are used primarily for measuring distances. In the Gale design of alidade, none of these hairs is adjustable with respect to the others, but the whole reticule may be moved by means of the four screws which hold it in place.

It is very important for purposes of adjustment to understand how the capstan screws control the movement of the cross-hair ring. . . . The holes in the telescope through which the screws pass are not threaded; on the contrary, they are a little larger than the screws, so that when the latter are loose the whole ring may be turned slightly by moving the four capstan heads simultaneously around the outside of the telescope until one cross-hair is vertical and the other horizontal. When the capstan screws are tight, each screw presses a curved washer against the outside surface of the telescope. When one screw is loosened and the opposite screw tightened, the whole ring is drawn toward the tightened screw (since the holes in the shell of the telescope are smooth) until the loose screw and its washer are brought into contact again with the outside of the telescope. Notice that before tightening one screw the opposite screw should be loosened, otherwise the ring cannot move and the screw-thread may be stripped. By loosening the lower screw and tightening the upper screw, the whole ring may be drawn upward, or by reversing the process it may be drawn downward. Likewise by working the side screws in a similar manner, it may be drawn to one side or the other. All this may be done without turning the ring, i.e., one hair may be kept vertical, the other horizontal.*

* J. C. Tracy, "Plane Surveying." John Wiley and Sons, New York City, *1907*, p. 550.

3. *Parallax.*—

If the image formed by the object-glass is not in the same plane with the cross-hairs, any movement of the eye is likely to cause an apparent movement of the image with respect to the cross-hairs. This is called parallax. The effect is similar to that produced in looking through a window, where any movement of the eye causes an apparent movement of objects outside. Parallax may render accurate work impossible. To remedy it the image and the cross-hairs must be brought into the same plane. Two steps are necessary.

(1) Point the telescope toward the sky and move the eyepiece in or out until the cross-hairs are as well defined as possible, i.e., in perfect focus. . . .

(2) Direct the telescope to the object and focus the object-glass as usual, keeping the eye on the cross-hairs until the image appears in sharp focus. Test by moving the eye from side to side, and if necessary move the object-glass slightly until parallax disappears.

The more accurate the work the more care should be used to eliminate parallax, while the higher the power of the telescope the more difficult it is to do this.*

4. *Collimation.*—The line of sight through the telescope is determined by the intersection of the cross hairs, whatever their position in the tube, and the nodal point in the objective lens. This line is correctly collimated when it coincides with the optical axis of the objective. That is, the intersection of the cross hairs should remain stationary in the field of vision when the telescope is rotated on its horizontal axis. Most telescopes are mounted between 180-degree stops in the axis-sleeve for this purpose.

Sight some distant fixed object of small size and center the cross hairs exactly upon it. The telescope need not be horizontal. Rotate the tube carefully half way round and twist the prismatic eyepiece back into position. Note whether the cross-hairs are still centered upon the object. If not, correct half the discrepancy by means of the diaphragm adjusting studs, which may or may not be concealed beneath a ferrule which forms a guard against accident or tampering. In figure 2, let the original position of the cross hairs be represented by lines passing through the point A, their position after rotation of the telescope by the lines passing through the point B, and their collimated position by the lines passing through the center of the circle. Move the vertical hair to left or right by turning both lateral studs

* J. C. Tracy, *loc. cit.*, pp. 555–6.

in the same direction, first slightly loosening the one, then tightening the other. If the alidade is of the erecting type with field reversed from right to left, as is commonly the case, loosen the screw away from which the vertical hair must apparently be moved, and tighten the opposite screw. Move the horizontal hair up or down by turning top and bottom studs in the same direction, first slightly loosening the one and then tightening the other. If the eyepiece is of the erecting type, loosen the screw towards which the horizontal cross hairs must apparently be moved and tighten the opposite screw. Having corrected half the discrepancy in this way, shift the alidade until the

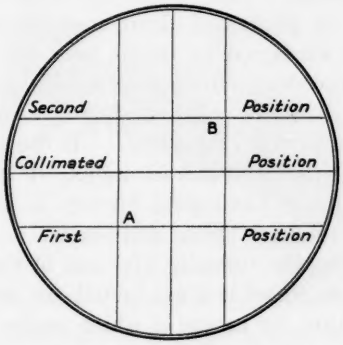


FIG. 2. DIAGRAM ILLUSTRATING THE ADJUSTMENT FOR COLLIMATION

cross hairs are again centered upon the distant object, and rotate the telescope as before. The line of sight should now remain fixed upon the distant point; if it does not do so, correct half the apparent error as before. Repeat until the hairs are properly centered.

The test for collimation should be made frequently. No important triangulations should be begun until one is certain that the cross hairs are properly located. Should the instrument be subjected to any unusual jar, it must be collimated before it is used again. In the normal routine of field work the position of the cross hairs should be examined at least once each week—preferably daily.

5. *The Vertical Movement and Arc.*—The telescope and axis-sleeve are carried on standards of varying height which permit a reasonable vertical swing of the telescope. On one side (usually the right) the transverse axis projects beyond the standard bearings and is gripped by the vertical clamp. This clamp is tightened or loosened by a knurled-head screw set close to the top of the right standard. When this clamp is loosened, the telescope swings freely through an arc of about 45 degrees, in a plane at right angles to the transverse axis. When the clamp is tightened, the vertical swing of the telescope is limited to the play of a tangent screw which gives a short smooth run of vertical slow-motion. This screw is often called the micrometer screw. A graduated drum may be attached to this screw, which, as explained in detail later on (Paragraph 18), may be used in the determination of vertical angles and in the measurement of distances. When thus equipped the tangent screw is called the "gradienter screw." If the special gradienter drum provided with a celluloid index, devised by Eugene Stebinger of the U. S. Geological Survey, is attached, it is referred to as the Stebinger Drum and Screw.

Fixed to the opposite (usually left) end of the transverse axis just outside the standard is a graduated arc, generally of about 130 degrees duration, by means of which angles of elevation and depression are measured. This is known as the vertical arc. It moves past a shorter arc, carrying a vernier scale, which is attached to the sleeve carrying the telescope. This vernier may be adjusted by a tangent screw, working through the left standard in much the same way as does the micrometer screw on the right standard.

The vernier is an auxiliary scale on which there are 30 graduations occupying a space equal to that of 29 graduations on the main scale. That is, each division on the vernier is just one-thirtieth smaller than a division on the main scale. If, therefore, the zero line of the vernier is directly opposite a line on the main scale, no other line on the vernier scale will coincide with a division of the main scale except the thirtieth. If, then, the arc be moved one minute (= one-thirtieth of one division) to the right, the first line on the left of the vernier zero will coincide

with a line on the main scale; if the arc be moved 15 minutes to the right, the fifteenth line on the left of the vernier zero will coincide with a line on the main scale, etc. On this principle the arc graduated only to half degrees may be read in minutes. On an arc graduated from right to left, read the highest division to the right of the vernier zero line; this will be either an even degree or a degree plus 30 minutes. Observe which line on the vernier coincides with a line on the main scale; add its value in minutes to the reading of the main scale. For example: the vernier zero is between the 24° 30′ and 25° graduations of the main

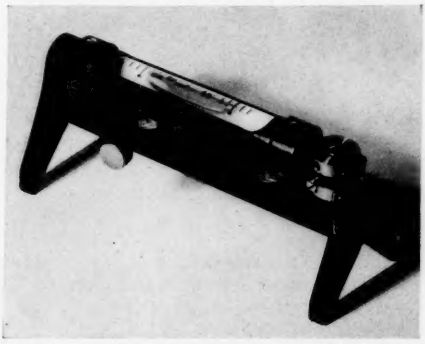


FIG. 3. THE STRIDING LEVEL, REMOVED FROM THE ALIDADE

scale; line 16 on the vernier coincides with a division of the main scale; the arc reading is therefore 24°46′.

6. *The Striding Level.*—The telescope tube is inserted in a short sleeve at its midlength, which forms a part of the transverse axis by means of which vertical oscillation is made possible. The telescope is mounted revolvably between 180-degree stops in this axis-sleeve, and is prevented from turning on its longitudinal axis in the process of focusing either by a plunger at the under side or by a clamp ring screwed at one end of the sleeve. At either side of this axis-sleeve the telescope is surrounded by a "red metal" collar, accurately turned to the axis of rotation defined by the sleeve. These collars are for the support of the striding-level by means of which the telescope is brought into the plane of the horizon. The striding-level is removable (Fig. 3)

and when not in use is held in a corner of the base plate by a binding post. A similar post is attached to the top of the axis-sleeve and when the striding level is put in place for observations it is snapped down over the shoulder on this post, which merely prevents it from falling off in case the alidade is tilted and should not support it in any way. The wyes, (which support the level) trued to the same angle, at either end of the bubble-glass then rest on the metal collars.

The striding level itself is a glass vial, partially filled with a non-freezing liquid, ground on the inside of the arc of a circle with long radius.

> The more uniform this curvature is throughout the length of the tube the more regular will be the motion of the bubble, and the greater the radius of curvature the greater the sensitiveness of the bubble. Within reasonable limits the more sensitive the bubble the more perfect the work, though a very sensitive bubble may be too unsteady for many purposes; on the other hand a sluggish bubble, though it may give the appearance of steadiness to an instrument, and an impression that it "keeps" its adjustment, is incapable of accurate work. . . .
>
> The line tangent to the circular arc of the tube at its middle point or a line parallel to this tangent, is called the axis of the bubble-tube. When this axis is horizontal the bubble will be in the center of the tube. Should the axis become slightly inclined the bubble will move toward the higher end of the tube in proportion to the angle made by the axis with the horizon. The glass tube is usually graduated on top by marks 0.01 feet (or 2 mm.) apart. The value of a level-bubble is usually expressed by the change which takes place in the inclination of the axis when the bubble moves over a single space. Thus in a 1-minute level, for a displacement of one division the inclination changes 1 minute, and in a 20-second level it changes 20 seconds.*

Ordinarily, the alidades in use by geologists are fitted with 60-second levels, but it is preferable where possible to use a 20-second level, a change which at low cost adds greatly to the possible accuracy of the work. However, the magnification of the telescope and the sensitivity of the level bubble should be kept consistent. A 10-second level mounted on an instrument equipped with a vernier reading only to minutes would be as absurd as a theodolite with a 60-second level the micrometers of which read to seconds of an arc.

7. *The Vernier-Control Level Bubble* is standard equipment on

* J. C. Tracy, *loc. cit.*, p. 544.

almost every modern make of telescopic alidade. Provided that the instrument has been properly adjusted for collimation and that the bubble and vertical arc vernier are in proper alignment, the vernier-control bubble completely eliminates the necessity of the striding level and greatly accelerates field work. This level bubble, graduated with as great accuracy as is consistent with the power of the telescope, is mounted rigidly on the top of the vertical arc (Fig. 4). A ball and socket joint at one end and a capstan-head screw at the other permit the occasional

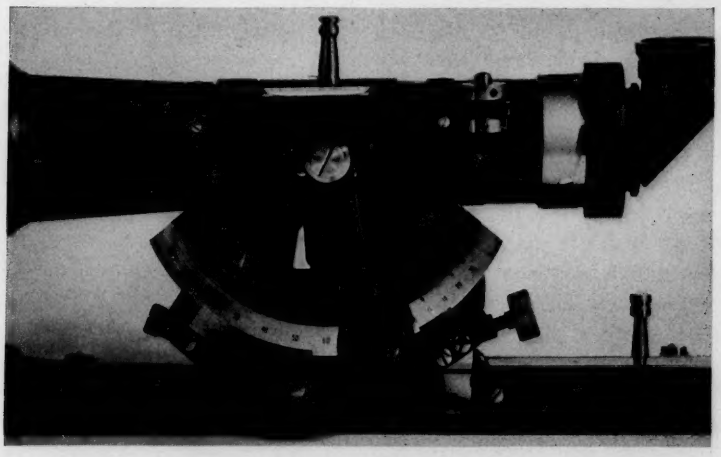


FIG. 4. THE VERTICAL ARC EQUIPPED WITH VERNIER CONTROL LEVEL

small adjustment necessary. When in proper alignment and ready for use, the bubble should come to rest in the center of its run when the alidade has been placed upon an absolutely horizontal surface and the vernier of the vertical arc indicates an angle of exactly 30°. (In certain of the more recent instruments this reading will be 0°.)

The vertical-arc-and-bubble unit may be rotated about the axis of the instrument, by means of a tangent screw, *without in any way disturbing the position of the telescope.* The vernier, however, which works along this vertical arc is attached to the telescope and maintains a fixed relation to its optical axis. In

order to make a vertical angular reading on any object, it is merely necessary to adjust the telescope until its horizontal cross-hair cuts the object. The tangent-screw controlling the vertical arc and bubble is now slowly rotated until the bubble is level. The vernier will now give the exact angular reading of the object quite regardless of any slight inclination of the surface of the table.

8. *The Fiducial Edge and Parallel Rule.*—The base plate is firmly attached to the telescope standards and is primarily intended to form a straight edge, parallel with the line of sight through the telescope and maintaining that fixed relation no matter in what direction the instrument is pointed. To facilitate the use of the straight edge, the right side of the plate is beveled and graduated in linear measure; it is known as the fiducial edge.

An "extra" attachment which has proved to be a great time- (and therefore money-) saver is the parallel rule, shown in figure 1. A brass straight-edge, 0.5 inch wide and as long as the alidade base, carries two brass bars, 1.00 or 1.25 inch long, pivoted near either end, with the pivot centers in a line parallel to the straight edge. Set in the free end of each short bar is a round lug which fits into a circular hole bored in the base plate near its margin. The centers of these holes are in a line parallel to the fiducial edge, and the short bars are of equal length. Therefore, the removable straight-edge, when put in place, is parallel to the fiducial edge and may be shifted close to it or out away from it without losing its parallelism. In "lining-in" a *distant station*, all the time involved in getting the fiducial edge exactly on the occupied station point is saved. The line of sight is mechanically shifted in parallel position to the proper place on the map. Similar holes may be bored near the left side of the alidade base, and the same straight-edge attached there for work close to the left margin of the table, but if that change is made, the table must be re-oriented because of the probable change in the relation between the line of sight and the ruler edge. It is vitally important to bear in mind on *all short sights* and *especially in large-scale work* (50 feet to the inch or larger)

that the telescopic line of sight and the fiducial edge of the ruler cannot both be directed simultaneously at the distant station that is being lined in. This *horizontal parallax* increases directly with the increase in width of the ruler. With a parallel rule extended to its maximum a very large parallactic displacement may result on a short sight. Great care must be taken to allow for this error and to correct it. The only way in which this can be accomplished is to place the alidade, when making a sight, as nearly as possible so that the optical axis of the telescope is *directly over* the observing station on the field sheet. A ray is now *lightly* drawn along the fiducial edge of the rule and then transposed, *parallel to this preliminary ray*, so that it may emanate from the true point of observation. The parallel rule, when detached, may be conveniently carried in a pocket sewn across one edge of the alidade case.

9. *The Compass and Bull's-eye Level.*—In the miniature alidades there is attached to one corner of the base plate a compass box, or declinatoire, housing a compass needle which has a possible oscillation of about 10 degrees. The compass is not intended for the reading of angles of departure from magnetic north, but solely for the designation of the magnetic meridian; therefore the only markings are the zero points at either end of the needle. The needle is either of the tubular or the steel-bar variety, mounted generally on a sapphire-tipped pivot, and provided with clamping device and adjustable balance. The latter must be adjusted by the user for different latitudes by sliding it along the needle until it is properly balanced. A declinatoire so constructed as to make the needle easily accessible is therefore preferable. There is also fixed to the base plate, generally near the objective end of the telescope, a bull's-eye level by means of which the plane table on which the alidade is resting may be quickly brought into an approximately level attitude.

PART II. ORIENTATION

10. *Introduction.*—In traversing with plane table and alidade, the location of an unplotted point is determined by its direction

and distance from another point which has previously been plotted on the plane-table sheet. Instead of determining this direction in terms of a compass or angle reading, to be later drawn on the map in the office, as is done with transit or theodolite, the determination and plotting of the bearing to the distant point are accomplished by a single operation. This makes necessary the accurate orientation of the plane-table sheet so that the lines drawn on it will, whenever the plane table is set up for use in the field, be parallel to the position which they occupied at every preceding set-up.

11. *Setting Up.*—The accuracy with which a plane table must be placed over a station of known position depends entirely upon the working scale of the field sheet. It is of particular importance to note, in the case of short sights and large-scale work, that the vertical parallelism, normally existing in small-scale work, between the telescopic line of sight ruled on the field sheet and the same theoretical line in nature is destroyed if the table is merely centred over the occupied station. Generally speaking, in surveys employing a scale of 50 feet to an inch or greater, the plane table must be set up and oriented so that the point occupied in nature is plumbed directly below the corresponding point on the sheet. Except in this case of excessively large scale, and in the event that a good many short sights must be made, regardless of scale, it is the usual custom to set up the tripod so that the center of rotation of the table is plumbed over the occupied station.

The plane-table tripod is usually equipped with a Johnson Head (Fig. 5), a device working on the ball-and-socket principle to the top of which the table is securely screwed. Two wing-nuts control the movement of the table after it has been fastened to the head. After the surface of the table has been carefully leveled with the bull's-eye level provided on the alidade for this purpose, the upper nut will clamp it securely in this level position, but will still allow it to rotate freely for orientation. After the table has been oriented (see Par. 12), the lower nut is tightly clamped and survey work may be started.

12. *Orientation.*—Orientation of the plane table is the adjust-

ment of its surface so that any line which may be drawn upon the field sheet is parallel to this same theoretical line in nature. This is normally accomplished in one of four different ways.

(*a*) *Simple Backsighting* is the easiest and most common method of orientation. This method can be used only when one occupies a station A, the position of which is known and plotted on the field sheet. Another station B must also be plotted on the sheet and must be unmistakably visible. To orient by this method after the table has been properly set up and leveled over A: place the fiducial edge of the alidade so that it lies on both station A and station B and the telescope points toward B.

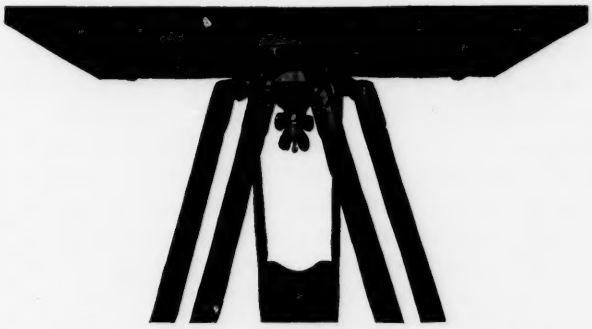


FIG. 5. JOHNSON HEAD TRIPOD AND PLANE TABLE

Now making certain that the lower clamp of the Johnson head allows free rotation, turn the table slowly until B in nature is intersected by the vertical cross-hair. Tighten the clamp securely and the table is oriented. Take great care that the table is not thrown slightly off orientation by the clamping of the head. *After* the head has been clamped be certain that B still lies on the vertical hair-wire. *To check:* if the position of a third point C is plotted on the sheet and also visible in nature, place the alidade along AC on the field sheet, with the telescope directed toward C. On looking through the telescope, C should appear exactly on the vertical cross-hair if the table is properly oriented.

(*b*) *Resection* is the method of orientation and position determination used when the observer has set up at a point not already plotted on his field sheet. This is commonly known as the *Three-Point-Problem*. For the purpose of brief discussion it may be divided into two separate cases, the first of which is not true 3-Point Resection but merely a special case of Backsight on two points.

1. When the observer occupies a position which has previously been sighted *for direction only* from one station A, and this and one or more other plotted points are visible in nature: after leveling, place the alidade along the "foresight" ray previously drawn from A and somewhere upon which the occupied station P is known to lie. The object end of the telescope should be directed toward A as it lies upon this foresight line. Now turn the table until A is picked up on the vertical cross-hair and clamp tightly. The table is now oriented. To obtain the position of the occupied point P which must be known before further detail may be added: place the object end of the ruler on B (the second plotted control point) and slowly rotate the alidade until B is picked up in nature. Make certain after this rotation that B is exactly on the fiducial edge of the ruler (*it never will be* and will always require a small correction). Then draw a ray *from B* toward the eyepiece end of the alidade. This line will intersect the first or orienting ray at the exact position of the observer P. Great care should be taken to choose a point B the ray from which will cut the orienting ray if possible at an angle no less than 20 degrees. A very small angle of intersection is sometimes inevitable but will obviously result in a rather unreliable position of the observing station. The position of P may further be checked by sighting off at any other visible control if it is available.

2. When the observer occupies a point P which has not previously been sighted from any station and the position of which is entirely unknown: at least *three* plotted control stations must be visible.* This is the true Three-Point-Problem so well known

* Resection may be accomplished in an unknown position from which only two control points are visible. This problem, known as "Two-Point-Resection" requires another table set-up and its solution is particularly involved.

to the geographical engineer. A detailed knowledge of its solutions should be at the finger-tips of every geologist engaged in plane table survey as it involves a situation which is very commonly encountered. There are a number of well-known solutions to the Three-Point-Problem. Only two of these can be discussed in so short a space.

The table must first be oriented as accurately as possible by compass (see paragraph on magnetic orientation). It is then clamped temporarily in this initial position and rays are drawn from the three control points A, B and C, toward the observer's hypothetical position. If the table has already been accurately oriented by means of the compass, *these three rays will intersect in a point P*—the true position of the observer. If not, the rays will form a triangle whose size will depend entirely upon the accuracy of the magnetic orientation. This triangle is known as the *Triangle of Error.*

By rotating the table slightly to the left or to the right this triangle may be resolved to a point. The position of P can be estimated at sight by skilled observers from the shape and the position of the triangle of error. The solution of the problem is more difficult for an inexperienced surveyor, but can always be obtained accurately if four axioms are kept in mind.

First: If the Triangle of Error lies *inside* the triangle which can be drawn by connecting the three control points A, B and C, the *position P is inside the Triangle of Error.*

Second: If the triangle of error lies *outside* the triangle formed by lines joining A, B and C, *the true position of P lies outside the Triangle of Error* and in one of the two sectors to the left or to the right of all the rays. (The left or right of a ray is determined when one looks along this ray toward the point from which it emanates.)

Third: In either Case One or Case Two, the final position of P is found by the law: the distances measured perpendicularly to P from the three rays which form the triangle of error are exactly proportional to the lengths of these rays (Fig. 6).

Fourth: There is no possible solution for the Three-Point-Problem if the three known points A, B and C and the observer's true position P lie on or even approach the circum-

ference of a circle. This is known as the *Revolver Case.* It is surprising how frequently this case may occur. The experienced surveyor invariably tries to avoid it by choosing for his control points three stations which could not possibly fall on the same circle with P, as in figure 6.

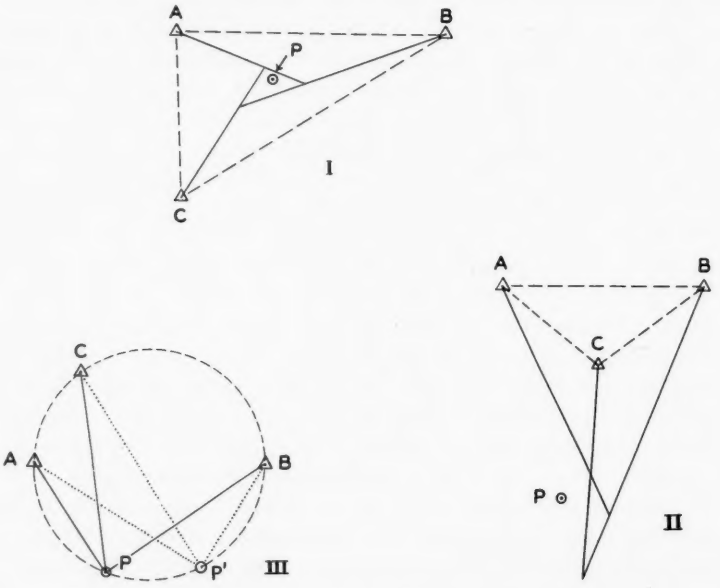


FIG. 6. DIAGRAMS ILLUSTRATING THE "THREE-POINT PROBLEM"

I, plane table is within the triangle formed by joining the three fore-sight stations, *A*, *B* and *C*; the true location, *P*, is within the "triangle of error"; *II*, plane table is outside the triangle formed by joining the three fore-sight stations, *A*, *B* and *C*; the true location, *P*, is outside the "triangle of error"; *III*, the "revolver case."

There are a number of graphic solutions for the Three Point Problem, the most frequently used of which is here explained in brief. The table is set up and roughly oriented by use of the compass. Next, a sheet of tracing paper or frosted celluloid, approximately the same size as the plane-table sheet, is placed on the table and temporarily secured with scotch tape. An

arbitrary point on this sheet is chosen in any appropriate place and labeled P. Next, assuming that P is the observer's position (*completely disregarding the field sheet underneath*), draw rays from P to A, B and C, the three visible control points. If more than three stations are visible, four or five rays will result in a much more precise location than three. This overlay sheet is now unfastened and slid around on the surface of the field sheet until a position for P is found which allows all the rays drawn on the overlay to pass directly over their respective control points on the field sheet. The true P thus found is lightly pricked through the overlay to the field sheet and the table finally oriented and checked by backsight to the control points.

Warning! The most likely place for error to enter into this manipulation is in the adjustment of the alidade base to the various backsight rays during the final process of orientation. A pocket magnifier should be used in placing the instrument if the most accurate results are desired.

(*c*) *Magnetic Orientation* is by far the most commonly used in surveys of flat country where previously established control is difficult if not impossible to pick up. Especial care must be taken not to rely too strongly on this system in mountainous areas or regions where local magnetic attraction is known to be present. This method is used extensively in reconnaissance survey of oil fields.

Compass orientation is accomplished by means of the trough or box compass which is customarily attached to the base of the alidade. The fiducial edge of the alidade base is placed along a line ruled on the plane-table sheet, and the needle liberated from its rest so that it swings freely in its box. The table is then rotated until the needle points to the north and south marks at either end of the compass box. Thereafter, whenever the same alidade is placed on the same side of the same line so that the same edge of its base coincides with the line, and the table is rotated so that the freely vibrating needle comes to rest at the same point, the sheet is in approximately parallel position. The orientation line ruled on the plane-table sheet should extend the full length of the alidade base, or should consist of two

shorter lines, three or four inches in length, drawn to each extremity of the base. An arrow should be sketched at the north end of the line or lines. The compass box is so attached to the alidade that when the needle comes to rest in the line of the marks at its ends the line of sight through the telescope leads approximately toward magnetic north.

Although of course not necessary, it is very desirable and universally customary to draw the orientation line so that the sides of the plane-table sheet coincide with the four cardinal directions. This may be accomplished in several ways, a few of which will be mentioned here. In many parts of the country, the public roads have been accurately surveyed along section lines; commonly the fences have been similarly placed in a true north-south or east-west direction. Again, section corners may be so situated that one corner-post, or a flag placed directly above it, may be seen from another. If the plane table can be set up in the line thus determined by road or fence or land net, the ruler-edge of the alidade should be placed along the margin of the plane-table sheet, or along the line previously drawn to represent the meridian of the map, and the table rotated until the line of sight through the telescope falls along the visible line thus defined. The table locked in that position, the alidade is moved to the desired part of the sheet and turned until the compass needle comes to rest in the line of its indicators. The orientation line is then ruled along the alidade base. The angle between that line and the meridian of the map will be determined by the local magnetic declination as modified by any divergence which may be present between the line of sight of the alidade, the fiducial edge of the alidade base, and the line defined by the compass needle and its indicators. These three lines need not be parallel; the work will not be affected by divergence between them.

Another method of orienting the table before drawing the orientation line makes use of a Brunton or other compass, care being taken to make allowance for the departure of magnetic from true north, and depends upon previous knowledge of the magnetic declination in the region.

It is often desirable to draw the orientation line on the plane-table sheet before it is oriented for the first time. It must then be assumed that the line of sight, the compass line, and the alidade straight-edge are parallel. In most cases the error in orientation thus involved will be of no consequence. The orientation line is plotted so that the angle between it and the meridian line is equal to the magnetic declination. This angle may be scaled off by means of a protractor, or if more accurate drafting is desirable, a trigonometric function may be used. Draw a line 10 inches long in the desired position of true north; at one end erect a perpendicular such that its length in inches is 10 times the tangent of the angle of declination; connect the other end with the end of the perpendicular by a line which is the desired orientation line. This is more accurate than plotting the angle with a protractor which has a radius of only 3 or 4 inches, for in that case any error in plotting is greatly multiplied when the line is extended to the necessary length of 12 or 15 inches.

The whole matter of accurate situation of the orientation line is of slight importance when working upon a plain sheet on which the land net has been previously plotted, or upon a base map prepared by other surveyors, as for example an enlargement of a portion of a United States Geological Survey topographic map or a Land Office map.

The use of the magnetic needle for orientation of a plane-table sheet requires the utmost care. The length of the needle from its pivot to either end is only $1\frac{1}{2}$ to 3 inches, and lines will frequently be drawn on the map which are much longer than that. Errors in observing the needle may therefore be multiplied during the progress of the work and thus may become of more than trivial importance. Careful attention should be paid to see that the needle is swinging freely; a pocket magnifier should be used in observing its position with respect to the indicators; observation should be made from directly behind the instrument so that the observer sights along the needle from above rather than from the side.

In many instruments the needle is not perfectly straight, or the two indicators and the needle pivot are not in a straight

line. It is then best to regard only one end of the needle, being careful always to use that end and not the other. Or again, the needle points may be blunt and the indicators of considerable width. In that case select a definite relationship of needle point to marker and adjust the table or alidade so that the needle always returns to that relationship each time the map is oriented.

The surveyor, moreover, must be always on guard lest steel or iron bodies in proximity to the compass box deflect the needle. Articles about his own person should receive his attention. He should stand so that his pocket knife is at least a foot from the needle. A Brunton or other compass must be kept at least 3 feet distant and must, therefore, be removed from the belt before attempting to orient the table. The margin of safety for a geologic hammer is a little less than 2 feet, and it may therefore be left in the belt if carried in the rear and if the surveyor stands well away from the table in observing the needle. A seemingly harmless leather-covered metal binocular or monocular case, if permitted to come within 2 feet of the needle, may lead to the erroneous conclusion that one is endowed with a superabundance of personal magnetism. Metallic bodies in the general vicinity of the plane table may deflect the needle and introduce grave errors into the work. The table should never be set up for compass orientation within 10 feet of a wire fence, within 15 feet of a pump-jack, less than 10 feet away from a pipe-line—buried or on the surface—, closer than 10 feet to a railroad track, or nearer than 20 feet to an automobile.

(*d*) *Other Methods* of orientation depend upon azimuth or geographical direction as determined from the various celestial bodies. One of the most common of these methods makes use of the Baldwin Solar Chart. The angle between the apparent position of the sun and true north is graphically determined by means of this chart which is so constructed that, when turned until the proper pivot point on an arrow and the "sun-time point" on a latitude arc are on a line parallel to the shadow cast by a plumb-line upon a level table, the arrow points true north. A copy of this chart and full directions for its use may be found in Topo-

graphic Instructions of the United States Geological Survey, pp. 136 to 141.

13. Radiation or "Lining-in" Stations is started as soon as the table has been set up, leveled and oriented. The bearing of any visible object may now be drawn directly on the field sheet. The alidade is moved until the straight edge touches the side of the needle hole or pencil dot representing the occupied station and the vertical cross-hair in the telescope bisects the distant object, the bearing of which is desired. A line drawn along the straight edge will then represent the compass-bearing plotted to position on the map under construction.

The best method to pursue in lining-in a distant station is to grasp the ends of the alidade base with either hand; shift the instrument until the line of sight through the telescope falls upon the desired objective and the fiducial edge rests within an inch or two of the dot locating the occupied station; then move the alidade diagonally forward and to the right, keeping the vertical cross-hair on the distant object, until the ruler edge touches the proper point. If the alidade is equipped with a parallel-edge ruler, it is only necessary to place the instrument somewhere near and to the left of the plotted point in such a position that the vertical cross-hair cuts the distant station. Then push the parallel straight-edge outward until it touches the proper point.* Some surveyors make it a practice to stick a needle vertically into the plane table at the point representing the occupied station, and to pivot the alidade on the needle when lining-in a station. This practice is not recommended. Although it is an easy way for the novice to increase his speed, it involves inaccuracies of considerable import. If the needle is inserted far enough to hold its upright position, it makes a hole several times as large as necessary; the point becomes a space which on the customary scales represents an area on the ground, 30 to 60 feet in diameter.

Lines representing bearings should be drawn with the chiseled edge of a 9-H pencil, being careful always to hold the pencil

* Note—When using the parallel rule, especial note should be made of the warning of horizontal parallax given in Par. 8, p. 13.

at the same angle and to see that the contact of rule and paper is perfect. Too hard a pencil must not be used for plane-table work in extremely damp regions or in rainy weather. Under such conditions it is best to use a 3-H or 4-H pencil and keep it constantly sharpened to a fine point. A small strip of sandpaper tacked to the under side of the plane table is very handy for this purpose. By placing the ruler edge in a position tangential to the tiny circle formed by needle hole or dot, the line when drawn should exactly cut the center of the "point". If the distant station is to be occupied subsequently and orientation there is to be by back-sight, the fore-sight line should be the full length of the alidade base; if not, the fore-sight line may be short, covering only the estimated position of the point.

It is better not to draw lines through the dot or needle hole representing the occupied station; break the line for a fraction of an inch on either side. Otherwise, by constant drawing and erasure of rays the point marking the observer's position is liable to become obliterated and the paper immediately around it may become badly scraped or torn. Never draw longer rays than necessary—the only valuable part of a ray is the spot at which it intersects with another.

It is often particularly helpful to know the scale value of the width of a sharp pencil line. The following are the approximate linear values in feet for the width of lines drawn with a carefully sharpened 4-H pencil on maps of several different scales:

$$\frac{1}{250{,}000} = 212 \text{ feet} \qquad \frac{1}{62{,}500} = 52 \text{ feet}$$

$$\frac{1}{30{,}000} = 25 \text{ feet} \qquad \frac{1}{20{,}000} = 17 \text{ feet}$$

$$\frac{1}{10{,}000} = 8 \text{ feet} \qquad \frac{1}{5{,}000} = 4 \text{ feet}$$

PART III. MEASUREMENT OF DISTANCE

14. Distances may be measured with the telescopic alidade in several different ways. The methods applicable when the line of sight is nearly horizontal will be considered first.

(*a*) *The Stadia Method.*—Horizontal distances may be found directly by means of the stadia hairs and stadia rod. Stadia work depends upon the hypothesis that the sizes of objects required to produce an image of fixed size in the telescope are directly proportional to their distances from the point over which the telescope is set. This hypothesis is not rigidly correct, but the theoretical error is small and the practical error negligible. The limits of the image in the telescope are fixed by the parallel stadia hairs in the reticule. The object most convenient to use is a graduated rod. In the alidades commonly used by the geolo-

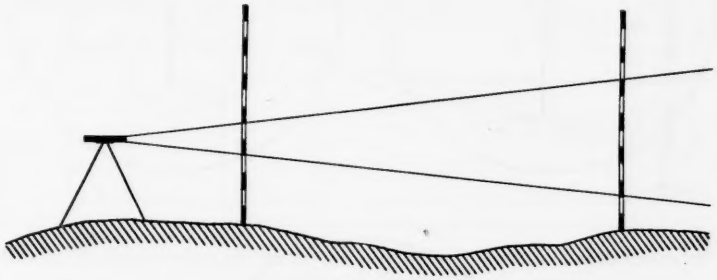


FIG. 7. DIAGRAM ILLUSTRATING THE STADIA PRINCIPLE

The diverging lines representing the projection of the stadia hairs form intercepts on the rods proportional in length to their distance from the instruments.

gist, the stadia hairs are so adjusted that the ratio between the distance from the telescope to the rod and the distance intercepted on the rod by the upper and lower hairs, when the rod is held at right angles to the line of sight and to the hairs, is as 100 to 1. If the rod is 300 feet from the instrument, the outer hairs appear to subtend 3 feet upon it; if 1300 feet distant, 13 feet of the rod will appear between them (Fig. 7). Moreover, the middle cross hair in the reticule is placed as nearly as possible equidistant from the outer two. Therefore, the distance subtended on the rod by the middle hair and either outer hair is 1/200 the distance of the rod from the telescope. In some alidades, "quarter hairs" are placed so that they bisect the spaces between the outer and middle hairs. The ratio for them is,

of course, 1:400. With an instrument so equipped distances up to 400 times the length of the rod may be read directly. Sketches showing the relation of a stadia rod to the field of view at different distances are shown in figures 8, 9 and 10.

FIG. 8

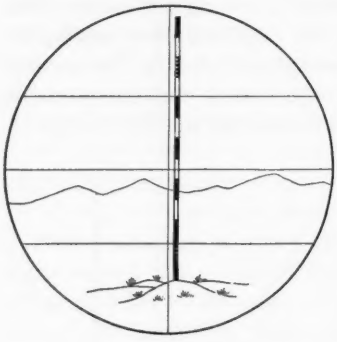
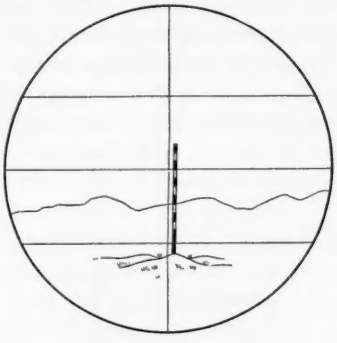


FIG. 9



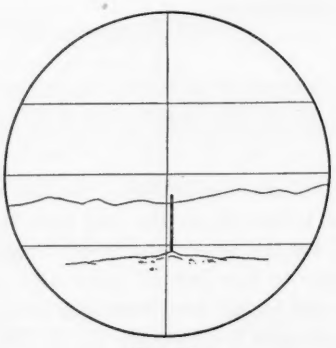


FIG. 10

FIG. 8. Stadia Rod in the field of view at a distance of 720 feet
FIG. 9. Stadia Rod in the field of view at a distance of 1740 feet
FIG. 10. Stadia Rod in the field of view at a distance of 3360 feet

In practice, then, it is necessary only to raise or lower the telescope until the two stadia hairs appear to rest on the rod, one intersecting a primary division and the other falling across a

divided foot. Read the intercept and multiply that distance by 100 if the outer hairs were used, by 200, if the middle and one of the outer hairs were used, or by 400, if the "quarter hairs" were read. Use the most distant hairs the intercept of which may be read, for otherwise the observational error is multiplied by 2 or 4, as the case may be. Also place the hairs as near the top of the rod as possible so as to minimize the error of refraction.

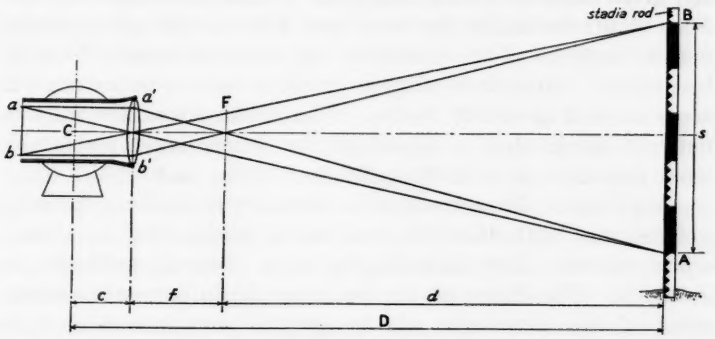


FIG. 11. DIAGRAM SHOWING PATHS OF LIGHT RAYS ENTERING TELESCOPE WITH EXTERNAL FOCUS

a and *b*; top and bottom stadia hairs; *C*, vertical axis of telescope; *a'* and *b'*, points in object lens at which rays projected from *a* and *b* are deflected; *F*, principal focus of telescope; *A* and *B*, points on stadia rod to which rays from *a* and *b* are projected through object lens; *S*, stadia intercept; *c*, distance from vertical axis to center of object lens; *f*, distance from center of object lens to principal focus; *d*, distance from principal focus to stadia rod; *D*, true distance from alidade to stadia rod.

As a matter of fact, the distance in the line of sight to the rod, thus determined, is not measured from the center of the instrument but from a point in front of the telescope objective at a distance equalling the focal length of the objective (Fig. 11). Therefore, the distance from center of alidade to rod is represented by the formula

$$D = Ks + (f + c)$$

where D is the distance to the rod from the vertical axis of the telescope; K is the stadia factor (usually 100); f is the focal

length of the objective; c is the distance, measured along the optical axis of the instrument, from the center of distortion of the object lens to the axis of rotation of the telescope; and s is the "stadia intercept" on the rod. f is constant for any given telescope and is usually marked, along with K, on the maker's inspection card. c varies slightly on account of small changes due to focusing. f + c is generally considered a constant for any given telescope and is called the "stadia correction". There is no stadia correction for telescopes with an internally focusing optical system. The correction for most externally focusing instruments varies from slightly under a foot to an extreme in some cases of about 20 inches. The stadia correction may be entirely disregarded in all except the largest-scale plane-table work greater than 1:2500 or 200 feet to the inch.

Long Sights. Occasionally it is necessary to measure distances greater than 200 times the rod length while using an alidade equipped with only three stadia hairs. Several methods are available. The choice of the one to use depends upon the equipment of the instrument, the geographic environment and the custom of the individual surveyors.

Two of these methods are, in effect, schemes to provide a longer rod, but depend upon the ability of the observer to rotate the telescope about its optical axis.

First. Rotate the telescope 90 degrees in its sleeve so that the stadia hairs are vertical instead of horizontal. Signal rodman to mark his station with a flag or to select a certain sapling or post for his station. Place one hair on the station and signal rodman to move *at right angles to the line of sight* until the rod, held vertically, is in line with the other stadia hair. The rodman will then measure the distance horizontally on the ground from his second position to his first, using the rod as a measuring stick, and report the result to the instrument man. Distances of 4000 to 7000 feet may be determined with a fair degree of accuracy by this method, which can be used on sloping as well as on horizontal ground. It may be used to advantage only when the two men are able to communicate freely by signals such as the two-arm semaphore code.

Second. Rotate the telescope as before. Signal rodman to hold rod horizontally and to be prepared to move laterally so that the base of the rod will occupy the point now occupied by its top. Intersect base of rod with one stadia hair. Signal rodman to move over in the desired direction a sufficient number of rodlengths so that the other stadia hair will finally intersect the rod. Read intersection; add the number of feet indicated by the length of the rod multiplied by the number of moves; multiply by 100 or 200 depending upon which hairs were used.

(*b*) *Stebinger System.*—If the instrument is equipped with a *Stebinger Drum*, three methods may be employed.

First. Place bottom hair on lowest visible primary division of the rod; read and record Stebinger. Turn Stebinger drum until middle hair rests on the top of the rod; read and record Stebinger. Take the difference of the two Stebinger readings; turn an equal number of divisions in the direction which brings the middle hair down onto the rod; observe the number of feet between the top of the rod and the intersection of the middle hair. Add this to the length of the rod which was above the bottom hair at the first reading; the sum multiplied by 200 is the horizontal distance. For example: 12 feet of the rod are entirely visible and the middle hair is well above the rod when the bottom hair rests 12 feet below its top. In that position the Stebinger drum reads 24. Turn down until middle hair touches the top of the rod; Stebinger reading is now 60. The difference between the two readings is 36. Turn down 36 divisions more, to 96. The middle hair now intersects the rod 3.4 feet below its top. The horizontal distance is $200 \times (12 + 3.4)$ or 3080 feet.

Second. If there is at hand a table, previously prepared for this particular instrument, showing Stebinger factors, i.e., the differences in elevation at the unit distance of 100 feet corresponding to the vertical swing of the telescope denoted in divisions of the Stebinger drum, proceed as follows. Place one hair on the top of the rod; read and record Stebinger. Turn down until that hair cuts the lowest visible primary division of the rod; read and record Stebinger. Take the difference of the two

readings. Repeat for each of the other two hairs. The three results should check. Select from the table the Stebinger factor corresponding to that number of divisions. Note the number of feet passed over on the rod; multiply it by 100 and divide by the factor. The result is the horizontal distance. For example: 13 feet of the rod are visible. With middle hair resting on the top of the rod, the Stebinger reading is 62. When the middle hair is turned down to the primary division 13 feet lower, the reading is 106. Difference of the two readings is 44; corresponding factor is 0.4111; horizontal distance is 1300 ÷ 0.4111 = 3160 feet.

This method is frequently employed by ingenious surveyors to good advantage in determining distances without the use of the stadia rod. Any two points, one above the other at known distances apart, suffice. Two flags at a measured interval, the crown plate and girths (commonly eight feet apart) of a standard derrick, the eaves and lower copings of a church tower, are listed merely as suggestions. If the location of such a target is plotted, the surveyor may "shoot himself in", with a fair degree of accuracy, at any point from which it is visible.

Third. The third method is probably best suited to the more common conditions met in geologic mapping. Place middle cross hair on top of rod; read and record Stebinger, denoting the record as A. Turn down until middle hair intersects the lowest visible primary division; read and record Stebinger (record B). Turn down until top hair rests on top of rod; read and record Stebinger (record C). Compute distance by the formula

$$D = 200r \frac{C - A}{B - A},$$

in which D represents the distance, r the length of the rod above lowest visible primary division, and A, B and C, respectively, the three readings of the Stebinger drum. For example: a 13-foot rod is entirely visible. The middle hair on top of rod gives a Stebinger reading of 31; middle hair on bottom of rod gives a reading of 54; top hair on top of rod gives a reading of 78.

$$\text{Distance} = 200 \times 13 \times \frac{78 - 31}{54 - 31} = 5300 \text{ feet}^*$$

(*c*) *The Micrometer Alidade.*—The micrometer eyepiece is a most valuable accessory to the telescopic alidade for certain types of surveys. Its value lies in affording much greater range in distance for sights than does the stadia eyepiece and in permitting the instrument man more freedom in making subsidiary stations about a principal station wherever a suitable targeted base can be erected. It is particularly valuable in making route surveys in open country, for there its full range may be utilized. This range is only limited by the power of the telescope and obstructions to sights. Another advantage scarcely less important is that it permits the observer himself, rather than a rodman, to visit side spots where he obtains better views of the terrain being surveyed than can be obtained from a single central set-up, from which sights are taken on a rod held in random positions.

The base to be employed may be either a graduated rod or a pole with cross bars erected in a vertical position, or a horizontal

* The formula may be more easily recalled if one has grasped the principle upon which it is based. The Stebinger difference, C − A, is theoretically a constant, the measure of the angle between the rays converging from the top and middle cross-hairs to the focus of the telescope. If the rod at the distant point were of sufficient length, the intercept subtended by this angle could be read and, multiplied by 200, would give the distance to the rod. That is, if i be taken to mean the length in feet of that hypothetical intercept,

$$i = D \div 200$$

But

$$i : r :: C - A : B - A,$$

for the Stebinger difference C − A is the measure of the angle defined by the chord i and B − A is the measure of the angle defined by the length of the rod at the same distance. Therefore,

$$(D \div 200) : r :: C - A : B - A,$$

or

$$D = 200r \frac{C - A}{B - A}.$$

or sloping distance measured between two targets on the ground. A pole 20 to 25 feet high with two sets of cross bars, oriented at 90° to each other and forming two divided bases 5 and 15 or 5 and 12 feet, erected at a station where it can be seen from every direction, gives the observer full opportunity to range over the terrain all about the target as far as three-quarters of a mile and to fix his position at any site he chooses for a side station. When there is but one assistant to act as rodman, recorder or handy man, this advantage acquires an added meaning. On route surveys, rock cairns or other suitable targets thrown up to form a base a few hundred feet long and oriented approximately across the direction of travel make it possible to read distances as great as several miles. The azimuth of such a ground base is suitably marked on the plane-table sheet (long line) and the horizontal or slope distance carefully measured. With this record the base can be used regardless of the azimuth of the back-sight to it, provided the component of the base at right angles to the sight is of appropriate length for the distance to be determined. In general the ratio of base length to distance should be large enough to obtain good advantage of the field of the telescope but not too large to prevent getting both targets (ends of the base) well inside the field. The ratio 1 to 100 is a suitable lower limit for a telescope whose field is 1 degree or more. Thus for a distance of five miles the base should be at least 250 feet long and may be as great as 400 feet; for ten miles, from 500 to 800 feet.

Micrometer eyepieces are equipped with both ordinary fixed stadia wires, and a traveling cross wire, which is moved by a revolving drum. In form, the eyepiece is similar to the micrometer microscope fitted to precise instruments for reading fractions of angles. It may be rotated about the axis of the telescope through an angle of 90 degrees, so that regardless of how much the base may slant with respect to the horizon, a setting can be made to cause the traveling wire to run perpendicularly across the base. A comb silhouetted in one side of the field of the telescope provides means for determining the number of complete revolutions of the drum without having to count them, or serves as a check on the count. In principle, micrometer

measurements are similar to those made by stadia with the difference that in stadia a graduated rod and wires fixed at a constant distance apart are employed, while with the micrometer a *fixed base* and a *movable wire* are employed.

Figure 12 shows a model of the telescopic alidade fitted with a micrometer eyepiece, which is designed for convenience and facility. It is also equipped with an auxiliary "vernier-control" level bubble—a valuable fitting if many vertical angles are to be observed.

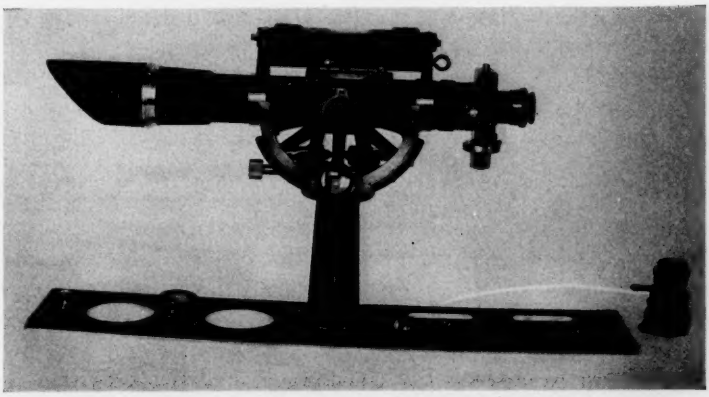


FIG. 12. ONE OF THE ALIDADES USED BY THE U. S. GEOLOGICAL SURVEY
This recently designed instrument, equipped with micrometer eyepiece, is the result of years of experience, and is largely due to the interest of Mr. R. H. Sargent, Chief Alaskan Topographer.

It is necessary to calibrate the micrometer before using it to measure distances. This consists in finding its constant or the value of the drum graduations. The calibration is done by testing the instrument at measured distances on bases of known length, a procedure similar to that followed in testing stadia wires.

The formula for use on level ground when the base is laid at right angles to the line of sight is:

$$H = \frac{B}{R} \cdot C$$

in which the focal distance of the telescope is neglected. H represents the horizontal distance to be measured; B the length of the base; R the drum reading; and C the micrometer constant. This formula is used in transposed form to determine the constant C.*

15. *Measurement of Distance (Inclined line of sight).*—The preceding discussion of the measurement of distances with the stadia has been based on the assumption that the rod is always held perpendicular to the line of sight and that the desired distance is to be measured along that line. As a matter of fact, most of the sights in stadia work are taken not on a level, but on a slope or inclination, as suggested in the diagram, figure 13. Consequently if the rod is held vertically, the stadia intercept is somewhat more than it would be when held perpendicular to the line of sight, and an element of error is introduced. This error amounts to 1 per cent of the distance for a gradient of 8 degrees, 2 per cent for 11 degrees, and 3 per cent for 14 degrees. It may obviously be corrected by having the rodman "wave" the rod slowly backward and forward while the observer takes the *least possible reading.* This will occur when the rod is held perpendicular to the line of sight. This may also be roughly accomplished by attaching a short pointer to the rod at right angles to its face and aiming this pointer at the instrument when the sight is taken. It is, however, difficult to hold the rod steadily in this position and this corrects only one of the two discrepancies. It is therefore customary to hold the rod vertical no matter what

* If the bearing of the base is not at right angles to the line of sight and α be the angle between the base line and the sight, the effective base becomes $B' = B \sin \alpha$. When a vertical angle V is also involved the right term of the formula must be multiplied by cos V. The general formula then becomes

$$H = \frac{B \sin \alpha \cos V \cdot C}{R}$$

A small error is introduced in the use of B sin α because the triangle involved is assumed to be a right angle triangle when it actually is not quite so. The angle subtended at the instrument by any base is so small however that the assumption is warranted and no appreciable error results from this source in reconnaissance or exploratory surveys.

may be the angle of slope and to make the correction in the tables for distance and elevation.

The second discrepancy is due to the fact that the distance to be plotted is the horizontal distance from telescope to rod, not the inclined distance. So far as plotting is concerned, this discrepancy, and therefore the angle of inclination, must be fairly large before it need be taken into account—how large depends upon the scale of the map. For most work it may be neglected for all angles of less than 3 degrees. With an angle of

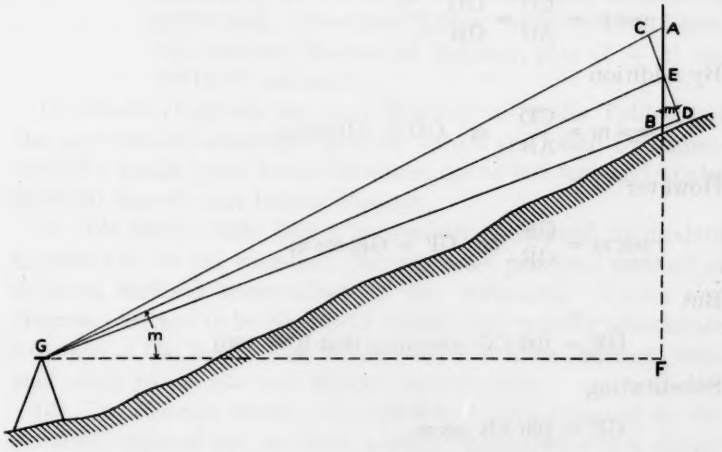


FIG. 13. DIAGRAM ILLUSTRATING THE STADIA PRINCIPLE APPLIED TO INCLINED SIGHTS

5.5 degrees this discrepancy amounts to about 1 per cent, which for a distance of 1000 feet is little more than the diameter of a needle hole on a scale of 1:31,250.

The stadia tables, stadia diagram and stadia slide-rule methods are commonly used to determine the horizontal component of an inclined sight. In practice, such tables should be consulted before plotting distances determined by sights which depart more than 3 degrees from the horizontal. Reference to the accompanying diagram (Fig. 13) will make clear the mathematical

formula upon which the correction tables are based. In the diagram, AB represents the intercept on the rod held vertically; CD the intercept on the rod held perpendicular to the line of sight from G; GE the distance from table to rod in the line of sight; and GF the horizontal distance from set-up to station. The angle of inclination of sight and the equal angle between the two positions of the rod are indicated by m. By trigonometry (assuming that, for all general purposes, the angles at C and D in figure 13 are right angles),

$$\cos m = \frac{CO}{AO} = \frac{OD}{OB}$$

By addition

$$\cos m = \frac{CD}{AB} \quad \text{or} \quad CD = AB \cos m$$

However

$$\cos m = \frac{GF}{GE} \quad \text{or} \quad GF = GE \cos m$$

But

$$GE = 100\ CD \text{ (assuming that } K = 100)$$

Substituting

$$GE = 100\ AB \cos m$$

But

$$GF = GE \cos m$$

Substituting

$$GF = (100\ AB \cos m) \cos m$$

$$GF = 100\ AB \cos^2 m \text{ [plus } (f + c) \cos m, \text{ if necessary]}$$

By means of this formula the horizontal distance may easily be computed from the rod intercept (*rod held vertical*) and the known angle of inclination of the sight. It is from this formula that the common *Stadia Tables, Stadia Diagram* and *Stadia Slide Rule have been prepared.*

(*a*) *Stadia Tables* consist of a series of horizontal numerical values computed for a stadia intercept of one foot when viewed on a rod held vertical, with the angle of the line of sight ranging from the horizontal to an inclination of 30 degrees. For distances under or over 100 feet, the correct figure for the desired angle may be taken out of the tables as a *percentage value* and multipled by the stadia reading to obtain the true distance.

Example: Stadia intercept of 3.28 feet read at angle of 18°10′. From Stadia tables we see that an intercept of one foot at 18°10′ would give a horizontal distance of 90.28 feet. Therefore $3.28 \times 90.28 = 296.12$ feet, the required horizontal distance, plus (f + c) cos 18°10′ if necessary.

(*b*) *Stadia Diagrams* are used similarly to Stadia Tables, but the approximate corrected distance values are found by inspection of a graph upon which distances up to 400 feet and angles up to 30 degrees may be read directly.

(*c*) *The Stadia Slide Rule* is universally considered by modern engineers to be the speediest and the most practical method of reducing inclined observations to the horizontal. Tables and diagrams are apt to be clumsy to handle and rapidly deteriorate from use in the field. The Stadia slide rule is, in contrast, compact, easy to operate and almost indestructible.

(*d*) *The Beaman Stadia Arc* which is etched adjacent to the standard vertical arc on most modern instruments is a simple attachment for the solution of the inclined stadia problem. This arc carries two scales, a Multiple Scale (labeled V) and a Reduction Scale (labeled H), having coincident zero points marked 50 and 0, respectively (see figure 18). The reduction scale is, of the two, the more distant from the adjustable index and gives percentages of correction that may be used to reduce observed stadia distances to horizontal. The adjustable index should be set opposite the zero of the reduction scale when the telescope is level. To get the necessary correction, simply read the same scale with the line of sight cutting the distant station. Reading to the nearest per cent is usually sufficient. For example: the reduction scale reads 3 with an observed rod intercept of

16.2; then 3 per cent of 1620 = 48.6; 1620 − 48.6 = 1571.4 = corrected horizontal distance.

16. *The Location of Stations.*—The distance thus determined by stadia is scaled off on the line ruled in the direction of the rod station from the point representing the occupied station. The proper method is to place the fractional scale division on the plotted point and prick the new location with the needle, or mark it with a well-sharpened pencil, at the even division at the end of the scale. This operation should be performed with the greatest care and preferably with the assistance of a pocket magnifier. *More closure errors are to be attributed to careless plotting*

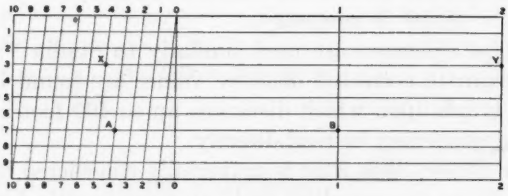


FIG. 14. THE DIAGONAL SCALE

Although constructed with a ruler graduated only to tenths of an inch, distances may be measured accurately to hundredths of an inch; $AB = 1.37$; $XY = 2.43$.

than to any other cause. If a needle is used, do not try to puncture a hole clear through the paper; push the needle point just far enough into the paper to make a permanent indentation, being careful to hold the needle vertically.

For the accurate measurement of distance on the field sheet a ruler divided into decimal parts of an inch, and preferably to hundredths, is most heartily recommended to facilitate plotting. If a minutely divided decimal scale is not available, the *Diagonal Scale* which has been so generally employed by the British Ordnance Survey, is extremely valuable. This scale can be constructed most rapidly and accurately in any unused corner of the field sheet and completely obviates the necessity of any kind of ruler. A pair of dividers is all that is necessary for transferring to various parts of the map the distances measured off upon the scale in its corner. The diagonal scale shown above has been

constructed with a ruler labeled only to tenths of an inch, yet upon it two distances have been found accurately to hundredths of an inch. (XY = 2.43 inches; AB = 1.37 inches)

17. *Accuracy of the Stadia Method.*—The telescopic alidade and stadia rod are to be looked upon as instruments of precision. Distances are not estimated, but accurately determined in well-conducted stadia work. Although essentially intended to secure rapidity rather than accuracy, the stadia method employed with due care to eliminate the chief sources of error is capable of attaining a high degree of accuracy.

PART IV. DETERMINATION OF DIFFERENCE IN ELEVATION

18. *Methods of determining differences in elevation* by means of the telescopic alidade are even more numerous than those in vogue for measuring distances. The good instrument man will know several different methods and select the one best suited to the particular sight, depending upon the accuracy required, the inclination of the sight, the equipment of the instrument, and the necessity for speed. The more commonly used methods will be described in the order of their simplicity.

(*a*) *Direct Rod Readings.*—Occasionally the difference in elevation between plane table and rod is so slight that with level telescope the middle cross hair intersects the rod. The vertical distance from the bottom of the rod, or from any other selected point on it, to the point of intersection may be read directly from the graduations on the rod's face. Care must be taken to prevent the confusion of the top and bottom stadia hairs with the middle cross hair. It is the visual ray projected by the middle hair that is parallel to the striding level and therefore is horizontal when the level bubble is centered.

But, suppose that when the instrument is level, the middle hair falls above or below the rod while one of the other horizontal hairs cuts the rod. In practice it is customary first to read the rod intercept for distance and second to determine the vertical difference between instrument and rod. Therefore, the operator has just measured the vertical distance between the visual rays projected by the cross hairs at the position occupied by the rod, The bottom hair, in figure 15, for example, cuts the rod at a point.

the distance of which below the point where the middle hair would intersect the rod, were the rod long enough, has just been determined. Similarly, the top hair in figure 16 intersects the rod at a known distance above the middle hair. Hence, if any of the three hairs rests on the rod when the telescope is level, the vertical difference between instrument and rod may be measured directly.

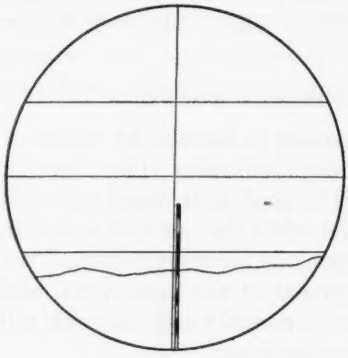


FIG. 15

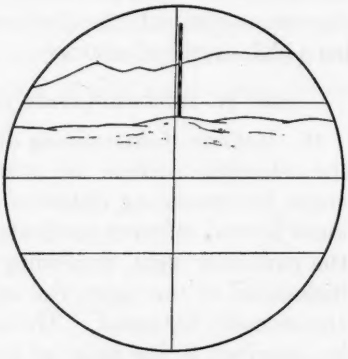


FIG. 16

FIG. 15. STADIA ROD IN FIELD OF VIEW WITH LEVEL TELESCOPE AT DISTANCE OF 1050 FEET

The base of the 13-foot rod is 14.8 feet below the elevation of the alidade

FIG. 16. STADIA ROD IN FIELD OF VIEW WITH LEVEL TELESCOPE AT DISTANCE OF 2140 FEET

The base of the rod is 8.9 feet above the elevation of the alidade

Examples are illustrated in figures 15 and 16. In the former, the horizontal distance has been read as 1050 feet and with level telescope the bottom hair intersects the rod 9.6 feet above its base, which is, therefore, 14.85 feet below the elevation of the instrument. In the latter, the horizontal distance has been determined as 2140 feet and with level telescope the top hair intersects the rod 1.8 feet above its base, which is therefore 8.9 feet above the alidade.

In practice it is only necessary to record the horizontal distance and the rod intersection, noting which hair intersects the

rod, with level sight. The vertical distance can be determined later by addition or subtraction.

(*b*) *The Step Method.*—The same principle may be extended to cover a much larger range of circumstances. Suppose the rod is so far below the elevation of the alidade that with level sight all three hairs project rays slightly above the top of the rod. Note where the middle hair intersects any fixed object in the field—a point on a nearby tree, or a certain rock on the distant hillside. Turn down the instrument until the top hair intersects the same object. The bottom hair now appears to be 1/100 the horizontal distance, previously determined by the stadia intercept on the rod, below the point where the middle hair had formerly been. If the bottom hair now cuts the rod, read its intersection and add that figure to 1/100 the horizontal distance to get the V. D. (vertical difference in elevation), which in this case, would be negative. If the bottom hair is still above the rod, note where it in turn intersects some fixed object in the field of vision and turn down the instrument until the top hair occupies its position. The bottom hair now appears to be 2/100 the horizontal distance below the point intersected by the middle hair with level sight. The process may be repeated, noting how many "steps" are used, until the bottom hair finally intersects the rod.

Obviously, the same method may be utilized for determining elevations of stations above the instrument by "stepping up" from the level sight until the top hair cuts the rod. Figure 17 illustrates the method. In recording observations it is only necessary to note the observed distance, the number of steps, the final rod intersection, and the sign of the V. D., plus for stations above and minus for stations below the instrument elevation. For example, a sight to a station 1760 feet distant, recorded as "+4 (steps) − 3.5", indicates that the base of the rod is (4 × 17.6) − 3.5, or 66.9 feet above the instrument. Or, a sight of 1320 feet with the V. D. recorded "−3 (steps) − 12.9" indicates that the base of the rod is −(3 × 13.2) − 12.9, or −52.5 feet in relation to the altitude of the telescope.

Attention should be directed again to the fact that the first

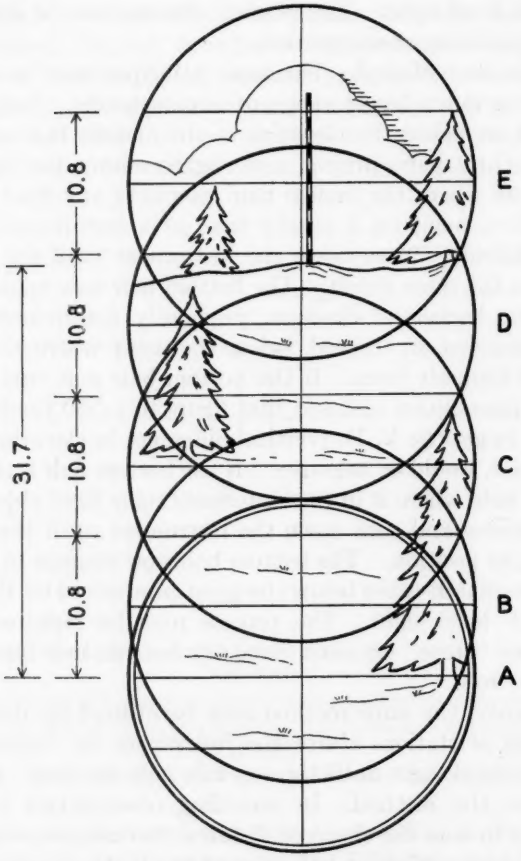


FIG. 17. THE STEP METHOD

Circle *A* encloses the field of view as observed through the level telescope. Circle *B* is the field after the telescope has been raised so that the bottom cross hair occupies the position occupied in *A* by the middle hair. *C* and *D* represent the second and third steps, in each of which the bottom cross hair rests in the position previously occupied by the top hair. In *D*, the third step, the top hair cuts the rod 0.7 feet above its base. The rod intercept, 10.8 feet, is indicated in *E*. The base of the rod is therefore $3 \times 10.8 - 0.7 = 31.7$ feet above the instrument.

"step" is in reality only a "half step" for by it one of the outer hairs is moved to the position occupied by the middle hair, whereas, each step, after the first, involves the movement of one outer hair to the position occupied by the other outer hair. This is compensated by the fact that the reading of the rod intersection after the final "step" is a reading of the position of an outer hair, not that of the middle hair. This makes the final "step" really a "step and a half" because the hair, the intersection of which is read, is a half intercept above or below the middle hair.

The "step" method when used by an experienced instrument man is very fast and fairly accurate. It is not, however, sufficiently accurate for important work, as there is wide margin of error involved in the placing of one hair in the position previously occupied by another. Moreover, there is no simple way of correcting the error resulting from the inclination of sight to the rod when the intercept is read. The "step" method should never be used when more than 6 steps are necessary, nor to determine the elevation of a turning-point or set-up. It is well fitted to serve as a check upon the more accurate methods next described, when there is need for especial care to guard against error.

(*c*) *Vertical Arc Determinations.*—Other and more accurate methods of measuring the difference in elevation between two stations depend upon the determination of the vertical angle between the line of sight from one station to the other and the line of sight through the level telescope.

The angle of inclination of the line of sight to the target may be read in degrees and minutes by means of the vertical arc. With loosened clamp the telescope is raised or lowered until the middle cross-hair rests *near* the selected target. The clamp is tightened and by means of the tangent screw the middle hair is accurately placed on the target. The point on the vertical arc opposite the zero of the vernier is read to the nearest minute and recorded. The telescope is then leveled, first loosening the clamp if desired, and the bubble in the striding level centered by adjustment of the tangent screw. The point on the vertical

arc now opposite the vernier zero is read and recorded. The difference between the two readings is the desired vertical angle.

The graduations of the vertical arc differ on alidades of different manufacture, but one of the common graduations is indicated in figure 18 by the markings on the left half of the arc. The main scale of the arc is divided into degrees and half degrees. By means of the vernier it may be read in minutes. (See Par. 5.)

A vertical angle of 1 minute subtends a chord of 0.3 feet at a distance of 1000 feet. Hence it is imperative that no mistake be made in selecting the vernier division which coincides most closely with a line of the main scale. Most surveyors make it a practice always to use a pocket magnifier in reading the vernier.

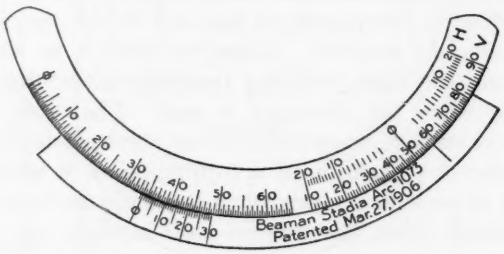


FIG. 18. THE BEAMAN STADIA ARC, SET TO SHOW A POSITIVE DIFFERENCE IN ELEVATION OF 8 TIMES THE OBSERVED STADIA DISTANCE

Most modern telescopes have traveling magnifiers permanently attached to the vertical arc. It is also easier to detect offsets of the main scale and vernier division lines if one looks obliquely along the lines at an angle of 30 or 40 degrees with the face of the scale than it is when observing the vernier face from a direction perpendicular to it. The most common of the serious errors which may involve the vernier reading is to overlook the 0.5 degree division of the main scale and count it as an even degree. Guard against that blunder by computing the position of the vernier zero twice for each angle.

Most alidades are equipped with adjustable vernier and with main scale so graduated that the vertical arc may be set to read 30°00′ when the telescope is level. A few of the most recent

instruments have a zero horizontal reading with elevation and depression scales departing from this origin in both directions. Among topographers it is customary, in reading vertical angles, first to level the instrument with the striding level and then set the vernier at 30°00′. Next the telescope is turned down or up for the reading on the distant object. It is then necessary to record only one angle reading—that made after the cross hair is set on the target. A reading less than 30°00′ indicates an angle of depression, one greater than 30°00′ an angle of elevation, if the arc is graduated from left to right.

This procedure is not recommended for petroleum geologists, however, because of inherent differences in the work of these two classes of alidade-users. In the topographer's party the lowest-paid man is ordinarily holding the rod on the station to which the sight is being taken. It is of little consequence whether he remains there four minutes or two. When he is moving on to the next station the topographer's time is occupied with sketching contours; he has no idle moments. In the petroleum geologist's party, the reverse is the case. The highest-paid man ordinarily holds the rod. The amount of work the party can do in a day is in inverse ratio to the length of time he is kept idle while the instrument man makes observations. While he is moving on to the next station, the selection of which will ordinarily require 10 to 20 minutes, the instrument man has nothing to do except compute his results—a task which, if necessary, may be done later in "the office". Moreover, the geologist's plane table is customarily lighter and smaller than that used by the topographer; it is seldom possible to get it in a precisely level attitude. Therefore it would be necessary to level the telescope and set the vernier after the geologist has occupied the fore-sight station and while he is waiting for the observations to be made. The procedure of the instrument man should be planned explicitly to minimize the length of time the rodman is kept at a station. Just as much of instrument work as possible should be done after the rodman has been "waved on". With this in mind, the instrument man signals the rodman as soon as the cross hair is set on the selected mark

on the rod. After the rodman has departed he reads and records the vernier, levels the telescope, reads and records the new position of the vernier, wherever it happens to be, and determines the vertical angle by subtraction. He is then under no pressure of haste in reading the vertical arc and in centering the level bubble. To increased speed of geologic work is added thereby greater accuracy in instrumental observations. The record, then, includes two angle readings, one on the target and one with level telescope; the sign of the angle, plus for stations above and minus for those below the altitude of the table; and the observed intercept on the rod. From these data the vertical distance may be computed at leisure.

Since the invention of the Vernier Control Bubble (Paragraph 7) almost all telescopic alidades have been equipped with this device, which permits the reading of vertical angles with great speed and accuracy, and obviates all calculation or the use of the striding level, except for occasional checking purposes, in the field.

By referring to Figure 13 a formula may easily be derived which will give the elevation of any station whose inclined stadia rod reading and angle of elevation are known.

(From paragraph 15)

$$CD = AB \cos m$$

$$\sin m = \frac{EF}{EG} \quad \text{or} \quad EF = EG \sin m$$

However

$$EG = 100\ CD \quad \text{or} \quad 100\ AB \cos m$$

Substituting

$$EF = 100\ AB \cos m \sin m$$

or

$$EF = 100\ AB\ \tfrac{1}{2} \sin 2m\ [\text{plus } (f + c) \sin m \text{ if necessary}]$$

1. *The Vertical Angle* and this formula may be used in the field for determination of difference in elevation between stations, but this method is extremely inconvenient, demanding a

considerable amount of figuring and consultation of angular function tables for every sight.

2. *Stadia Tables* for difference in elevation have been computed and are usually published together with the tables for horizontal distance described in paragraph 15.

Example: Stadia intercept of 3.28 feet read at an angle of 18°10′. From Stadia Tables we see that an intercept of one foot at 18°10′ inclination would give a difference in elevation of 27.62 feet. Therefore $3.28 \times 27.62 = 97.15$ feet, the required difference in elevation.

3. *The Stadia Diagram* may be used for speedy and approximate graphical determination of difference in elevation in exactly the same way as for the computation of horizontal distances (Par. 15).

4. *The Stadia Slide Rule* is fully as swift and accurate a means for the determination of difference in elevation between stations as for the determination of horizontal distance (Par. 15).

(*d*) *Beaman Stadia Arc.*—The reading of vertical angles may be avoided by the use of the Beaman stadia arc, illustrated in figure 18. This is a specially graduated vertical arc which may be attached to the vertical limb of a transit or telescopic alidade. It carries two scales, of which the one nearer the adjustable index is known as the multiple scale because it indicates multiples for obtaining differences in elevation. The zero point of this scale is marked 50 and its divisions are so spaced as to be proportional to one-half the sine of twice the angle through which the telescope moves.

To determine differences in elevation read the distance subtended on rod and express in feet (for example, 8.7 = 870 feet). Clamp telescope and level. Set index exactly at 50, by means of the tangent screw back of arc, and do not touch this tangent screw again.

Then by means of the customary clamp and tangent movement, raise or lower telescope until there is brought exactly opposite the index such a graduation on the multiple scale as will throw the middle stadia wire somewhere on the rod, it does not matter where. The arc reading, minus 50, multiplied by the observed stadia distance gives the difference in elevation between the instrument and a known point on the rod—that is, the height on rod indicated by middle wire. Settings of both index and arc should be made carefully under reading glass.

Example: Suppose observed stadia distance is 6.3 (630 feet) and that telescope is so inclined that multiple scale reads 58, at which exact setting the middle wire on rod reads 7.2 (7.2 feet above base of rod), then multiple is 58 = 50 + 8, and computation for a fore sight would be

$$\begin{array}{r} 6.3 \\ \times 8 \\ \hline +50.4 \\ -7.2 \\ \hline +43.2 \text{ feet} = \text{base of rod above H.I.} \end{array}$$

If middle wire were set on H.I. or top or other fixed point on rod and the arc were read by estimation (for example, 54.2) to obtain a multiple, the result would be approximate only; therefore this method is not to be used with this attachment.

If the half-wire interval is read and this reading is then doubled to get the stadia distance, it occasionally happens that no even multiple arc setting which will throw middle wire on rod can be found. In this case make arc setting that will throw the lower wire anywhere on rod; the middle wire will then be somewhere above the top of the rod. Then take multiple as read on arc, but compute position of middle wire above base of rod by adding one-half the expressed stadia distance (in feet subtended) to the reading of the lower wire.

Example: If the half wires subtend 7.2 on rod, the distance would be 7.2 × 2 = 14.4 (1440 feet). If the lower wire cuts the rod 8.7 feet above its base, the computed middle wire reading would be 8.7 + 7.2 = 15.9 feet above base of rod. Then compute as before.*

The advantages of the stadia arc are readily apparent. The use of stadia tables, slide rules, or diagrams is entirely obviated, nor is there any vernier to be read. The accuracy of results is identical with that obtained from formula or table computations. In fact, differences in elevation may be read more closely than is possible where vertical angles are determined only to the nearest minute. Moreover the simplicity of the process eliminates many of the chances of error which are incidental to the use of other methods and gives final results in minimum time. The use of the arc is, however, limited to sights which involve the reading of the stadia rod, and for most "shots" it holds the rodman on the station longer than is necessary with certain other methods.

* Topographic Instructions of the U. S. Geol. Survey, Washington, D. C., Govt. Printing Office, *1918*, pp. 131–2.

If it is desired to use the Beaman stadia arc principle with an instrument not regularly equipped for such work, the ordinary vernier arc may be used by reference to the following table,

*Table showing angular values of Beaman intervals**

NUMBER OF INTERVAL	ANGLE		DIFFERENCE IN MINUTES	NUMBER OF INTERVAL	ANGLE		DIFFERENCE IN MINUTES
	°	′			°	′	
0		00.00					
			34.38				36.16
1	0	84.38		16	9	19.89	
			34.39				36.42
2	1	08.77		17	9	56.31	
			34.42				36.70
3	1	43.19		18	10	33.01	
			34.47				37.00
4	2	17.66		19	11	10.01	
			34.52				37.32
5	2	52.18		20	11	47.33	
			34.59				37.71
6	3	26.76		21	12	25.04	
			34.68				38.08
7	4	01.44		22	13	03.12	
			34.77				38.49
8	4	36.21		23	13	41.61	
			34.88				38.95
9	5	11.09		24	14	20.56	
			35.02				39.44
10	5	46.11		25	15	00.00	
			35.16				39.97
11	6	21.27		26	15	39.97	
			35.33				40.54
12	6	56.60		27	16	20.51	
			35.50				41.16
13	7	32.10		28	17	01.67	
			35.71				41.85
14	8	07.81		29	17	43.52	
			35.92				42.58
15	8	43.73		30	18	26.10	

* Reproduced by permission from Metro Manual, Bausch and Lomb Optical Co., Rochester, N. Y., 1915, p. 114.

which is also of use in checking the action of the Beaman scale. It is computed from the formula:—vertical distance = $\frac{1}{2}$ sine of twice the vertical angle, and gives values by which the Bea-

man intervals can be translated into angular valuations and vice versa.

(*e*) *Stebinger Gradienter Drum.*—The accuracy of a sensitive bubble vial in the striding level is greater than that implied by the reading of the vertical angle only to even minutes. The fine adjustment tangent screw is so threaded that a complete revolution deflects the telescope about 34 minutes, so that if the unit of measurement be 1/500 a revolution of that screw, the accuracy of reading vertical angles is greatly increased. This is especially important in determining the difference in elevation of a station two to eight miles away, as is frequently done in triangulation work. The Stebinger gradienter drum surrounding the tangent screw is graduated into 100 divisions, so broadly spaced that the drum may be read accurately by estimation to 0.2 division, and so quickly legible that there is marked saving of time and increased safeguard against error in observation when it is used in preference to the vertical arc. It is in reality simply another method of reading the vertical angle, denoting the angle by an arbitrary unit instead of by degrees and minutes. The value of that unit in length of chord at known distances may be expressed in tables similar to those provided for computation from vertical arc readings.

In most instruments a clock-wise rotation of the Stebinger drum depresses the objective end of the telescope by pressing against a little stud fixed to the inside surface of the right hand standard. A counter-clock-wise rotation permits a spiral spring to expand against the opposite side of the stud and thus to raise the objective end of the telescope. Experience indicates that it is unsafe to trust the spring to act with uniform regularity and smoothness. It is therefore necessary in using the Stebinger method always to read vertical distances in one direction—usually downward*—the direction in which the telescope is moved by clock-wise rotation of the drum. If the station is higher than the telescope, the first reading is taken with the horizontal

* In some instruments the screw is fixed to the telescope standard and the stud is attached to the arm of the clamp of the telescope axis; when so attached the direction of movement to be used in reading the gradienter is upward.

cross hair cutting the target. The telescope is then turned down to the level position for the second reading. If the station is lower than the instrument, the telescope is leveled for the first reading of the Stebinger drum and then turned down till the cross hair cuts the target for the second reading.

The fine adjustment screw to which the Stebinger drum is attached is a tangent screw; that is, its motion is tangential to the arc described by the arm of the clamp of the telescope axis. Therefore, a revolution of the screw, when it is near one of its limits of motion will elevate or depress the telescope through an arc slightly different from that resulting from an equal turn of the screw when it is midway between its limits. Therefore it is necessary always to begin an angle reading with the tangent screw in approximately the same position as that from which the determination of the Stebinger factors was made. This position, generally about a quarter turn of the screw after it first "takes hold", should be indicated by a mark on the celluloid or steel index. After each reading the tangent screw should be withdrawn to that position, ready for the next reading.

In practice, then, the first reading is made with the Stebinger drum somewhere near the predetermined starting point and with the cross hair on the distant object, if it is higher than the instrument or with the telescope level if the sight is a "down shot". The reading, a figure between 0 and 100, is recorded in the proper column of the note book. The telescope is then turned down by means of the tangent screw to position for the second reading. As the Stebinger drum revolves the total number of revolutions should be counted. The count may be verified by the graduations on the index bar if present and is set down at the left of the two digits which indicate the Stebinger division beneath the index. For instance, after completing 8 revolutions, the Stebinger drum is brought to rest at 67; the second reading is therefore recorded in the appropriate column as 867. With an alidade which "reads down", as is the more common arrangement, the smaller of the two Stebinger readings will be in the "Sight" column if the target is higher than the instrument, and in the "Level" column if lower than the instrument. The differ-

ence between the two readings expresses the size of the vertical angle in terms of Stebinger divisions. From the Stebinger tables prepared for the individual instrument the corresponding "Stebinger factor" is selected. This factor multiplied by the apparent distance gives the difference of elevation of target and plane table.

The preparation of the Stebinger tables is essentially the determination of the value of Stebinger units in terms of circular measure. Withdraw the micrometer screw to the position from which determinations of vertical angles will be started. Set the drum on an even division and read the vertical arc. Turn the drum through 100 divisions and read the arc again. Turn through 200, 300, etc., divisions, reading the arc at each hundred until the screw has reached the farther limit of its play. Usually 9 or 10 hundred divisions will suffice. Repeat the operation at least five times and take the average value in minutes for each hundred divisions. Determine the corresponding difference in elevation for each of these angles by interpolation of the regular stadia tables or from a table of natural sines by the formula: difference of elevation = $\frac{1}{2}$ sine of twice the angle. The first value thus determined divided by 100 is the difference in elevation corresponding to each Stebinger division between 0 and 100. The second value minus the first and divided by 100 is the difference in elevation corresponding to each Stebinger division between 100 and 200. The third minus the second and divided by 100 is the value for Stebinger divisions between 200 and 300, etc. Carry the quotients in each case to the fifth decimal. With an adding machine set at the difference in elevation for one division between 0 and 100, print 100 additions for the factors corresponding to the first 100 Stebinger divisions. Then with the machine set at the difference in elevation per division between 100 and 200, print 100 additions for the factors corresponding to the second 100 Stebinger divisions. Complete the table in this manner, changing the addition figure after each 100 additions. Number the divisions, strike out the extra decimals beyond the third for the first 50 divisions and beyond the second thereafter, and typewrite into tabular form in paral-

lel columns—the number of divisions in one column, the corresponding factors in another. Brief tables for correction because of curvature and refraction as well as for conversion of observed to horizontal distances should be added at the margin. The whole, if properly planned, will occupy a sheet about 5 × 7 inches in size when photographed to one-half reduction for field use.

A slight modification of the above method will give a still more accurate series of factors. Read the vertical arc at each 50th division of the Stebinger drum instead of each 100th; determine the corresponding difference in elevation for each Stebinger unit as before; with the factors thus obtained plot a curve using the numbers of divisions as the abscissas and the values as the ordinates. From this curve the point will be readily apparent at which the micrometer screw begins to work with reasonable uniformity; begin constructing the table to be used at that point. From the curve determine the points where the factors for two successive divisions differ by 0.00005 and compute the factors for the number of divisions represented by each of these points. Interpolate between the values thus obtained to complete the table.

The table of Stebinger factors should be checked every few weeks by comparing a half dozen Stebinger readings, made at haphazard intervals well distributed throughout the range of the micrometer screw, with the corresponding readings of the vertical arc. The Stebinger factor should be identical, on the average, with the vertical distance corresponding to the arc reading.

In reading the Stebinger drum the observation should be made from directly above the celluloid or steel index so as to project the index line vertically downward to the drum. Ordinarily, a reading to the nearest Stebinger division is sufficiently close, but for low angles and long "shots" it is better to estimate half divisions, and for the nearly horizontal two-to-five mile "shots" of triangulation it is frequently worth while to estimate to tenths of a division. For these long sights, the distance of which is determined by scaling off the space on the map, there

is a theoretical error in using tables based on the formula involving one-half the sine of twice the angle, but there is practically no discrepancy here, for the difference between the sine of a small angle and one-half the sine of twice that angle is negligible.

19. *Curvature and Refraction.* No matter what method of determining vertical distances is used, a correction for curvature and refraction must be applied to all "shots" of a mile or more in length. The level datum to which all elevations are referred is a surface having the curvature of the Earth. The line of sight through the telescope in a level position is tangential to this curved surface. Distant objects, therefore, appear lower than they really are. In the greatly exaggerated figure 19, for example,

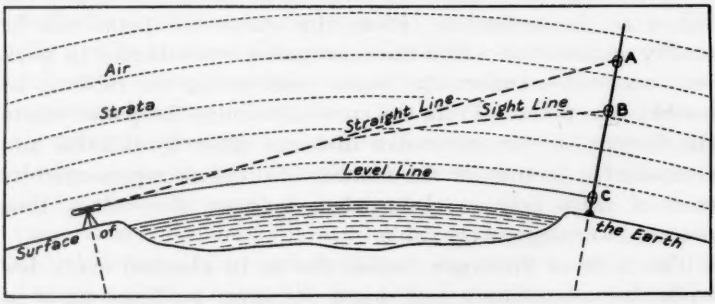


FIG. 19. DIAGRAM (GREATLY EXAGGERATED) SHOWING INFLUENCE OF CURVATURE AND REFRACTION UPON OBSERVATIONS FOR DETERMINING DIFFERENCES IN ELEVATION BETWEEN TWO POINTS

the rod reading is increased from C to A. The result of curvature can be determined with reasonable accuracy. It varies directly as the square of the distance and may be computed by the formula: curvature $= 0.667 \times D^2$, where D is the distance in miles.

Refraction, on the other hand, has the opposite effect. When light rays pass obliquely from one air stratum to another of different density they are bent or refracted from their original position. In figure 19, the light from the target at B, passing into air strata of increasing density as it travels to the alidade at the left, is bent downward and enters the telescope as though

it had come by a straight line from A. Thus, the effect of normal atmospheric refraction is to make distant objects appear higher than they really are. It, therefore, tends to decrease the curvature correction, as shown in the figure. The amount of refraction depends upon the density of the air and is, therefore, quite variable. It is much greater near the ground than 3 feet above it, and generally greater at midday than early in the morning or late in the afternoon. The empirical valuation ordinarily placed upon the effects of refraction gives the combined formula: curvature plus refraction = $0.57135 \times D^2$, or in a commonly accepted form = $4/7\ D^2$.

A table showing corrections based on this formula may be found in the ordinary stadia tables. The correction amounts to only 0.1 foot for distances of 2200 feet, 0.2 for 3125 feet and 0.5 foot for 4940 but increases rapidly to more than 5 feet at 3 miles and 20 feet at 6 miles. It may safely be disregarded for the great majority of rod "shots", which will doubtless average less than 3000 feet long.

The combined correction for curvature and refraction is always a positive quantity and should be added algebraically after the proper sign has been placed in front of the vertical distance as instrumentally determined, an angle of elevation having been given a plus and an angle of depression a minus sign. Thus the correction will *increase* the vertical difference for angles of elevation, and will *decrease* it for angles of depression. Occasionally, for nearly level sights the correction to be applied for curvature and refraction will be greater than the observed difference in elevation, but no confusion will arise if the rule stated in the first sentence of this paragraph is rigidly observed.

20. *Care and Adjustment of the Alidade.*—Like all instruments of precision the alidade must be handled with extreme care. Its metal parts are composed almost exclusively of brass, bronze, and "red metal", materials which are not notably resistant to abrasion. Precautions should constantly be taken, therefore, to keep the bearings free from gritty particles. *The instrument, for example, should never be placed on the ground or laid on a rock pile.* If for any reason it must be removed from the plane table,

return it to its leather case and close the case tightly before depositing it anywhere. The bottom must be kept clean. The instrument in its case should at all times be protected against jar and shock. The habit of dropping the alidade to the floor of an automobile to be shaken around in transit with hammers, specimens, tire tools and other impedimenta is indefensible. Treat it with at least as much consideration as one gives to lunch-kit and thermos bottles.

Once or twice a month, bearings, clamps and screws should be wiped clean with a cloth dampened in a light oil such as "3-in-1". The springs which play against the bearing studs on the opposite sides from the vernier and tangent screws should be removed from their housings, wiped clean, stretched a little and replaced.

If the Stebinger drum is used in determining the elevations, the tangent screw must be treated with special care. Experience indicates that very trivial and unobtrusive things may change the relation of the screw to the arc sufficiently to make a Stebinger table no longer applicable and necessitate the construction of a new one. If possible, the gradienter screw should be entirely withdrawn every week or two and wiped absolutely clean with the oily cloth. The bearing-plate stud against which the point of the micrometer screw pushes must be kept securely tightened. Should it become loose very erratic readings will result. The surface of this plate will gradually wear at the point where the micrometer screw bears against it until a distinct socket is made. Ultimately this becomes so pronounced that not only does it throw out the relation of the straight-line push of the screw to the circular movement of the arc, but the point of the screw will not hit exactly the same spot on successive readings, and as a result three or four readings from the same station to the same object will fail to check. When that happens, the bearing plate should be surfaced with a file and a new gradienter table constructed.

The compass needle should always be raised from its pivot and clamped immediately after it has been used. "Protect the pivot in every way possible, for unless the pivot is sharp and perfect the needle may be sluggish and unreliable." Place the

alidade as nearly as possible in the magnetic meridian before releasing the needle, and thus avoid the blow to the needle resulting from sudden contact with the compass box. The danger of destroying the polarity of the needle is another reason for guarding against reckless treatment of the alidade as a whole. When working in the rain, the compass box is the most vulnerable part of the instrument. Unless the glass cover is securely sealed all around, moisture will penetrate the box and put the needle out of commission by causing it to adhere to the inside of the glass. If this occurs, the box must be opened, the needle removed, and all parts thoroughly dried before proceeding with the work.

The most important adjustments of the telescopic alidade, which require attention in the field, are those for colimation and of the striding level. All other adjustments are reasonably permanent as made in the factory. It is, however, well for the instrument man to be able to detect, and if possible correct, faulty workmanship or damage from mistreatment or accident.

(*a*) *Parallax* which has been discussed in detail in Paragraph 3 is a very common occurrence and must constantly be expected. It should be remembered that, thoroughly to eliminate parallax, the cross hairs must first be focused against the sky or a light background before any attempt is made to focus the image seen through the object glass. Parallax is one of the easiest to detect of the several common maladjustments of the alidade.

(*b*) *Collimation* has been considered in detail in Paragraph 4. It must be borne in mind that, unless a telescope can be transited between observations, it must be perfectly adjusted for collimation or all the labor of careful leveling and accurate reading of the vernier will be of *absolutely* no avail.

(*c*) *The Striding Level.*—The line of sight when correctly collimated should be in absolute parallelism to the bubble axis, which is a line tangential to the curved surface of the striding level vial at the center of its scale. The two "red metal" collars which support the striding level are trued in the factory to the axis of rotation defined by the axis-sleeve within which the telescope rotates. There is very little chance for wear in the

sleeve and the collars themselves are subject to little or no wear, so that this adjustment is a fairly permanent one. The customary test of parallelism is therefore simple and rapid. Level the telescope by the striding level, then turn the level end for end on the collars. If the bubble does not come to rest in the same position as before, correct one half of the indicated error with the tangent screw and the other half in the striding level by turning the set screw in the crotch of one of the wyes with a screw driver. This will secure parallelism between the bubble axis and the contact points on the collars, but does not guarantee parallelism with the line of sight, although that has supposedly been provided for by the maker of the instrument. The reliable test is that of the peg-method described in most surveying manuals.

(*d*) *The Vernier Control Bubble* and its adjustment have been described in Paragraph 7. It is needless to say that if this bubble is at all out of adjustment, the results will be disastrous to all vertical angles that are read depending upon it.

(*e*) *The Bull's-eye Level.*—The inner surface of the circular bubble by means of which the alidade base is made to coincide approximately with the horizon is that of a sphere of long radius. The alidade base should be parallel to a plane which is tangential to this sphere at the point defined by the bubble indices. Once adjusted in the factory it is rarely necessary to rectify the bubble to keep this parallelism within the rather broad limits required for plane-table work, but if this necessity arises place the alidade upon a plane surface which is known to be level in all directions and tighten the screw toward which the bubble seems to creep.

(*f*) *The Stadia Constant.*—In alidades of the type customarily used by geologists, the distance between the stadia hairs is fixed in manufacture and may not be adjusted in the field. Occasional test should be made to ensure a close approximation to the fixed ratio of 1:100 between observed intercept on the rod and distance from alidade to rod. Read the rod intercept at accurately measured distances between 100 and 1000 feet from the instrument. If the stadia hairs do not give intercepts suffi-

ciently accurate for the work in hand, the discrepancy may be remedied either by preparing a specially graduated rod adapted for the particular alidade or by computing a constant by which observed distances must be multiplied in order to give true distances.

(*g*) *Telescope Axis.*—In order that the vertical cross hair shall travel in a vertical plane, the telescope axis must be adjusted to horizontality. The requirements for plane-table work are sufficiently met by the plumb-line test. Carefully level the plane table and place the alidade along a ruled mark. Hang a plumb line in the field of view and revolve the table to check against it. If the vertical hair deviates to the right for instance, reverse the alidade along the guide line and test on another plumb line swung in the new field of view. If in this case the vertical hair deviates an equal amount to the left, the test will show that while the plane table is not horizontal in the direction of the telescope axis, the axis itself is correct.

Adjustment of the horizontal axis, should this ever become necessary, cannot be made in the field. The factory adjustment is considered to be so permanent that an adjusting block is not provided on alidades. Moreover, it would be difficult to fit such a contrivance, for the vertical arc is on one extension of the horizontal axis and the vertical clamp is on the other.

(*h*) *Fiducial Edge.*—While it is not essential for the fiducial edge to be more than approximately parallel with the line of sight, it is important that this edge be straight. Draw a line against the straight edge and turn the alidade end for end. If the straight edge coincides perfectly with the test line, the requirements are satisfied.

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